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ASSESSING NATURAL MORTALITY OF ANCHOVY FROM SURVEYS' POPULATION AND BIOMASS ESTIMATES

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Abstract:
In ordinary catch at age models, natural mortality conditions and determines the catchabilities at age obtained for the surveys which tune the assessments. For the same reason, inferring the Natural mortality of a fish stock from surveys' estimates, require some assumption of the survey catchabilities at age. The anchovy fishery in the Bay of Biscay has been closed since 2005 up to 2010, due to low biomass levels. In the mean time, and since 1989, the population has been directly monitored by two independent surveys, acoustic and egg (DEPM) surveys, which supplied the basic information for the assessment of this stock carried out by ICES. The closure of the fishery supposes a major contrast on total mortality levels affecting the population in comparison with the former period of exploitation, suitable to get estimates of Natural and Fishing mortalities, under the assumption of no major changes in M occurring between both periods. Log linear models and a seasonal integrate catch at age analysis were tuned to the fishery and two series of surveys under the assumption of constant catchabilities across ages for the two surveys' population estimates. An analysis of the period 1987-2009, searching for a single and constant natural mortality at age, results in minimum residual SSQ for an M around 0.8. But a better result is obtained when a pattern of increasing natural mortality at age is allowed, a possibility suggested since a long time for this type of short living species.

Keywords: Anchovy; Natural mortality, M at age, Integrate assessment.

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1. Introduction

Natural mortality (M) is a key parameter scaling the outcomes from any assessment concerning population and biomass levels. Despite its relevance, it often has to be assumed due to the difficulties to estimate it separately from the fishing mortality (F) (Cotter et al. 2004). Even in cases when a direct monitoring of the population is made by acoustic or egg production methods, the distinction between M and F is hard to be made unless the catchability of the survey is known or assumed, and usually the total mortality Z is best assessed (Pope, . In the absence of proper estimates, indirect estimation of this parameter is made from available meta analysis of M from a wide range fish species, of different growth dynamics and environmental conditions (Pauly 1980, Gislason et al.2010). Certainly, the best method to estimate this parameter is analysing two periods of high contrast in the level of fishing mortality (i.e. fishing effort) as the difference in the total mortality should be proportional to the change in effort and this allows splitting fishing from natural mortality (Gulland 1983, Vetter 1988, Sinclair 2001, Wang et al 2009).

The life history of fishes suggest that natural mortality will change throughout the successive life stages from very high values in the egg larval and juvenile stages to medium or low values across its mature life span until an increasing natural mortality in senescence, and several models have been proposed to model this pattern at age of the natural mortality values (Chen and Watanabe 1988, Caddy 1991, 1996, Abella 1997). Short living species, as engraulidae, sandeels, capelin etc have usually natural mortalities higher than 0.6 in their adult phase (Gislason et al.2010) and for them the senescence increase of M is particularly expected to be noticeable (Beverton 1963). In some cases, as for sandeels, this increasing M with age has been evidenced (Cook 2004) and of course, an extreme case is that of capelin showing massive mortalities after their first spawning. One the major difficulty in evidencing changing natural mortalities with age is the confusion between differential catchability (and availability) phenomena with natural mortality patterns at age (Caddy 2001).

The Bay of Biscay anchovy is a short living species, rarely over passing its third year of life, which is yearly monitored by two independent surveys: an acoustic survey (Pelgas series –Ifremer-) and a Daily Egg production method (DEPM Bioman series –AZTI-). Both surveys supply biomass and population at age estimates, which constitute the basic information for the assessment of this stock carried out by ICES. This anchovy was assessed until 2004 by ICA (Integrated Catch at age analysis, Patterson and Melvin 1996) (ICES 2005), being subsequently assessed by a Bayesian two stage biomass model (Ibaibarriaga et al. 2008). In both cases natural mortality was assumed to be constant at 1.2. This value was inferred from the direct estimates of the population at age by the Daily Egg Production method (DEPM), under the assumption of unbiased absolute estimates of the population, and accounting for the catch removals (Uriarte 1996). While the Bayesian two stage biomass model assumes constant catchabilty at age of surveys, ICA calculated catchabilties at age for the surveys if demanded. When both surveys were assumed to give relative indexes of abundance, then their respective catchabilities at age were 50% higher for age 2 than for ages 1 or 3 (ICES 2005); this is a result hard to accept given the sufficient coverage of the surveys of the spatial distribution of the stock. Certainly an alternative explanation of that result could be due to a differential mortality at age of anchovies.

The closure of the anchovy fishery in the Bay of Biscay between 2005 and 2010, due to low biomass levels, give a unique occasion to check the actual level of natural mortality and the potential for a pattern of changing natural mortality at age. The closure of the fishery supposes a major contrast on total mortality levels affecting the population in comparison with the former period of exploitation, suitable to get estimates of Natural and Fishing mortalities, under the assumption of no major changes in M occurring between both periods.

In this paper we carry out an analysis to estimate the most likely natural mortality values of this anchovy population by two approaches: a) we first perform a direct analysis (by linear models) of the total mortalities between successive survey estimates of the population in numbers at age and analyse the changes between the period prior and after the closure of the fishery. This made globally for all age classes together and for the 1 or older age groups separately. b) Next, the natural mortality is also estimated by regression of the total mortality on an indicator proportional to F derived from the ratio of the catches over the average survey estimates of abundance. And finally c) An integrate catch at age analysis with a seasonal separable model of fishing mortality is applied to the analysis of the fishery in order to see what levels of natural mortality optimise the assessment, under the assumption of no differential catchability at age affecting the surveys.

2. Material and Methods

- **Data:**

Population at age estimates are available from the acoustic and DEPM surveys method. These estimates, in the way they have been provided to ICES, are split in either three (1-3+) or two age groups (1-2+). DEPM surveys, since 1987 and acoustic surveys since 2000 report population at ages 1, 2 and 3+ (with 3+ referring to three year old and older anchovies), whilst previous years of acoustic estimates report the population at ages 1 and 2+ (with 2+ referring to 2 year old or older fishes) (in 1989, 1991&92 and in 1997, Table 1). The surveys are carried in May at mid spawning time, when the bulk of the Spanish fishery takes place. For each survey and from every pair of consecutive population at age estimates, Zs,a estimates were derived for the ages 1 (from age 1 to 2), 1+ (from ages 1+ to 2+) and 2+ (from ages 2+ to 3+) as the log of the ratio of successive age classes in consecutive surveys (Table 2).

$$\ln\left[\frac{U_{a,y}}{U_{a+1,y+1}}\right]=\ln\left[\frac{N_{a,y}\cdot Q_{a,s}\cdot\exp(\varepsilon_{s,y})}{N_{a+1,y+1}\cdot Q_{a+1,s}\cdot\exp(\varepsilon_{s,y+1})}\right]=Z_{a,y}+\ln\left[\frac{Q_{a,s}}{Q_{a+1,s}}\right]+\varepsilon_s=F_{a,y}+M_{a,y}+\ln\left[\frac{Q_{a,s}}{Q_{a+1,s}}\right]+\varepsilon_s$$

$$\hat{Z}_{a,y,s}=\ln\left[\frac{U_{a,y,s}}{U_{a+1,y+1,s}}\right]=F_{a,y}+M_{a,y}+\ln\left[\frac{Q_{a,s}}{Q_{a+1,s}}\right]+\varepsilon_{y,s} \qquad \text{equation 1}$$

Notice from the above expression that the ratio of successive abundance indices of the same cohort will be equal to the total mortality Z only if the catchabilities of the successive age classes are equal. This is the first assumption we explicitly make in this study. In addition the larger the observation errors the poorer the estimates of Z will be. The second assumption made in the analysis is that the errors of the observations made by the surveys are log normal and of equal magnitude for both surveys (the requirement of homocedasticity for the ANOVA performed later).

Mean Z_{1+} estimates should provide an overall estimate of Z common to all ages, being roughly proportional to the relative abundance of age classes in the population, whilst Z_1 and Z_{2+} should provide indications of the level of total mortality for the one year old and older fishes respectively. Notice that changes in the Z between these two age groups for the period when the fishery was open can be due either to changes in the fishing mortality or in the level of natural mortality, provided the surveys do not show any differential catchability at age. However for the recent period when the fishery has been closed, Z equals M for all ages and any change in Z should be indicative of changes in M with age.

It should be noted that as surveys are made at mid spawning time, these Z estimates refer to the mortality occurring between successive spawning periods and not over the official year calendar.

IN order to make use of the whole set of data for the estimation of M through a linear model, an indicator of the fishing intensity for each year was estimated as the ratio of the catches between surveys and the mean abundance of the cohort between surveys. This follows from the catch equation:

$$C_{a,y} = F_{a,y} \cdot \overline{N}_{a,y} = F_{a,y} \cdot \frac{N_{a,y}}{Z_{a,y}} \cdot \left(1 - e^{-Z_{a,y}}\right) \Rightarrow$$

$$F_{a,y} = \frac{C_{a,y}}{\overline{N}_{a,y}} == \frac{C_{a,y}}{N_{a,y,s} \cdot \left(1 - e^{-Z_{a,y,s}}\right) / Z_{a,y,s}} = \frac{C_{a,y}}{U_{a,y,s} \cdot \left(1 - e^{-Z_{a,y,s}}\right) / Z_{a,y,s}} \cdot Q_{a,s} = RC \cdot f \qquad \text{Equation 2}$$

Where f is a coefficient of proportionality of the relative catches (*RC*) to F, which equals $Q_{a,s}$ the catchability coefficient when the mean abundance is known without error from the surveys. Notice that in order to make $N_{a,y}$ (the numbers at the beginning of the period) equal to the mean abundance in the period the required factor is $(1\text{-}exp(-Z_{a,y}))/Z_{a,y}$. This is a factor ranging between 0 and 1 and usually around 0.5. One inconvenience of this approach is that the fitted Z will appear in the independent covariate (RC). As a sensitivity analysis, alternative formulation of RC were made and essayed in this paper, as:

$$RCSurvey = \frac{C_{a,y}}{U_{a,y,s} \cdot \left(1 - e^{-Z_{a,y,s}}\right) / Z_{a,y,s}} \qquad \text{Equation 3}$$

$$RCSurvey2 = \frac{C_{a,y}}{\left(U_{a,y,s} + U_{a+1,y+1,s}\right) / 2} \qquad \text{Equation 4}$$

$$RCjo\text{int} = \frac{C_{a,y}}{\left[(U_{a,y,s=A} + U_{a,y,s=DEPM}) / 2\right] \cdot \left(1 - e^{-Z_{a,y,*}}\right) / Z_{a,y,*}} \qquad \text{Equation 5}$$

The second estimator takes as mean population abundance the mean of the abundances provided by the surveys at the beginning and the end of the period (i.e. the estimates of the cohort provided by the survey in year y and y+1).

The third estimator of RC tries to supply a single indicator of fishing intensity for each year based on both surveys estimates of the abundance at the beginning of the period and their mean *Z* ($Z_{a,y,*} = \left(Z_{a,y,A} + Z_{a,y,DEPM}\right) / 2$) for the period.

In all cases, the catches considered are those comprised between May 15 of year *y* and May 15 of year *y+1*, for the ages a and a+1 in each respective year. Original Catches at age (in numbers) with their mean weights are reported by seasons in ICES until the closure of the fishey in 2005 (ICES 2005).

- **Analysis carried out:**

a) Analysis of Variance of Total mortality (ANOVA)

We first test the consistency of the *Z* estimates by surveys across years for all ages

$$\hat{Z}_{a,y,s} = Age_a + Year_y + Survey_s + \varepsilon_{s,y} \qquad \text{(Models A1)}$$

With ***Age*** being the intercept for *Z1+* or a factor for the joint analysis of *Z1* and *Z2+**, Year*** and ***Survey*** being taken as factors.

Next, we tested the effect of closure on the overall levels of *Z* and by ages.

$$\hat{Z}_{a,y,s} = \overline{Z} + Fishing_i + Survey_s + \left[Old_a\right] + Interactions + \varepsilon_{a,y,s} \qquad \text{(Models A2)}$$

With ***Fishing*** indicating a period with fishing (***Fishing*** =0) or without fishing (***Fishing*** =1). ***Survey*** is a factor indicating they type of survey generating Z (DEPM=0 or Acoustics=1).

And ***Old*** being a factor reflecting whether age is 1 (***Old*** =1) or 2+ (***Old*** =1), put in brackets as it only appears when Z_1 and Z_{2+} are being analysed together, but not when dealing with Z_{1+}
Interactions are the potential first order and second order interactions of the former variables, which were initially checked.
Finally $\varepsilon_{a,y,s}$ is assumed to be a normal random variable $N(0,\sigma)$ common for all ages, years and surveys.

b) Linear models of Total mortality based on regression on the fishing intensity (relative catches) to obtain estimates of natural mortality.

Here the following model will be statistically tested for the different potential significant coefficients:

$$\hat{Z}_{a,y,s} = \ln\left[\frac{U_{a,y,s}}{U_{a+1,y+1,s}}\right] = M_{a,y,s} + F_{a,y,s} + \varepsilon_{a,y} = M + \left[m \cdot Old_a\right] + f_s \cdot RC_y + s \cdot Survey + Interactions + \varepsilon_{a,y,s}$$

(Models B1)

With ***M*** being the intercept, or natural mortality at age 1 (or 1+).
Old is a dummy variable being 0 for age 1 and 1 for age 2+, and ***m*** is the coefficient of increase of natural mortality for 2+ fishes. It is put in brackets as it only appear when Z_1 and Z_{2+} are being analysed together, but not when dealing with Z_{1+}
RC is the Relative Catches between surveys of the respective age *a* in year *y*. And ***f*** is the coefficient of proportionality of ***RC*** to *F*
Survey is a dummy variable being 0 for DEPM and 1 for Acoustics, and ***s*** is the coefficient reflecting any potential effect of the surveys on the Z estimates.
Interactions are the potential first order and second order interactions of the former variables, which were initially checked.

c) Integrated Seasonal Catch at Age Analysis tuned to the surveys (SICA model).

The convenience of using a Seasonal Integrated Catch at Age analysis (SICA) instead of the standard ICA software of Patterson and Melvin (1996) is that the latter is designed to operate on annual basis, while the former is designed to assess different seasonal fisheries, allowing at the same time to change the natural mortality within the year. In addition in SICA a Qflat catchability model is implemented for the purposes of this analysis (forcing catchability at age of the surveys to be equal for all ages), something not allowed in the standard ICA.

We have fitted SICA with the Qflat catchability model for the two surveys allowing to optimise for M1+ or for M1 and M2+, in order to find out what natural mortality pattern optimises the fitting. In practice, as the model is implemented in Excel, a systematic optimization procedure across a range of M1+ or M1 (optimising for M2+) was made. A M range between 0.4 and 1.7, in steps of 0.1, was covered. The results are the residual sum of squares (RSSQ) to the modelled input data throughout the range of M values, which jointly define a line allowing to look at the optimum range of M values.

SICA Details: The model is implemented in an ad hoc Excel work book designed for this fishery which fits a seasonal separable forward VPA to the Catches at age of five different fisheries operating over three periods of the year (ICES 2005), as follows:

Specifications of weights on the catches at age by Fisheries

	Relative weights at age:				INPUT **General Weighting factor for the fishery**
Seasons / Ages	**0**	**1**	**2**	**3+**	Relative to Spring Weighting factors
Winter Frech Fishery	0	1	1	0.5	0.24
Spring-French	0	1	1	0.5	0.14
Spring-Spanish	0	1	1	0.5	1
2nd Half of the year-France	0.02	1	1	0	0.73
2nd Half of the year-Spain	0.02	1	1	0.5	0.18

Seasons	Duración/Duration	
Winter	2.67	0.2225
Spring	3.33	0.2775
Semestre 2	6	0.5
Total (::12)	12	

The major fisheries are the Spring Spanish fishery and the 2nd half of the year French fishery which account for about 44% and 32% of the annual international catches.

Here below the average catches by fisheries and relative weighting factors in the assessment are presented:

1990-2004	France	Spain	Internation	France	Spain	International	Relative Weighting factors	
Averages	Catch	Catch	Catch	%	%	%	France	Spain
March	3080	0	3080	11%		11%	0.24	
June	1753	12597	14349	6%	44%	50%	0.14	1.00
2ndSemeste	9192	2320	11511	32%	8%	40%	0.73	0.18
Total	14025	14916	28941	48%	52%	100%		

Catches are modelled up to age 3+ (older ages are negligible) except for the French fishery of the 2nd half of the year for which a plus group is made from age 2+; this is made because up to 1997 null or few catches of 3 years old anchovies were reported, whereas afterwards they have been reported in non negligible quantities, giving an indication of different reliability of those catches through the period (therefore a plus group may be preferable in this case for fitting purposes). The fisheries can operate in parallel; as happens with the Spanish and French fisheries operating during the spring and 2nd half of the year. Catches in numbers and mean weights at age were reported in ICES (2005). Catches in tonnes are also used for the fitting, so that SOPs of modelled catches should match as much as possible actual catches. In this way this additional fitting terms act more as a penalty from deviation of cumulative catches, so that errors across ages in the fitting are somehow force to partly balance in order to still match total catches.

The modelled average population during the spring period is tuned to the Acoustic and DEPM spawning biomass and population at age estimates. The tuning indices can be used either as relative (linear models of catchability) or as absolute indices of abundance, similar to the choices allowed in the ICA assessment. In addition, for our analysis, the tuning indices (the DEPM and the Acoustic estimates) can be used as relative indexes with flat catchabilities at age, so that a single catchability by survey is estimated and applied equally to all ages. Both the population in numbers at age and Biomass (SSB) indices are used for the fitting. However, the fitting to SSB indices do not require a catchability parameter, because only the population at age estimates derived from the surveys are used to fit the catchabilities by survey. Modelled SSB as estimated by a survey is just the product of the modelled numbers at age estimates for the surveys by the weights at age in the population. In this way, consistency is assured between the catchability at age estimates and SSB estimates for the surveys. In addition, the residual sum of squares between the modelled and observed biomass by the surveys contribute to the total fitting even in the years when no age estimates from the surveys were available. This implies in turn that the years when only a biomass index is provided by a survey do not contribute to the fitting of the catchabilities at age. As such 14 out of 16 acoustic estimates are used for tunning the catchabilities at age (because the other 2 cruises have no age index). And for the same reason only 19 out of 22 cruises tune the catchability at age for the DEPM.

Inputs of seasonal Catches at age and populations at age estimates from surveys are assumed to have lognormal errors. Minimizations are made on log residuals.

Operating Model

Population at age:

Usual survival exponential model (Ricker 1975) and catch equation (Baranov 1918)

Separability model for fishing mortality defines for each age, year and period-fishery of the year

$$F_{a,y,p} = F_{ref,y,p}.S_{a,p}$$

Where $F_{ref,y,p}$ is the fishing mortality in year y and period-fishery p for the age of reference, which in this study is age 2 ($F_{ref,y,p} = F_{2,y,p}$) for all the seasonal fisheries.

$S_{a,p}$ is the selectivity for each age typical of every seasonal fishery and relative to the age of reference (age 2, which has a fixed selectivity value of 1).

Natural Mortality model

Natural mortality can be set fixed for all years and ages, or can be estimated (common for all years) and allowed to change for age 2+ as follows:

$$M_{2+} = M_1 \cdot Mfactor_{2+}$$

Mfactor$_{2+}$, if included, is estimated and kept constant across years. This factor applies by the first time to age 2 during the second half of the year, i.e. just after the spring estimates of the population by the surveys. In this way the parallelism between the M estimates in the log lineal models above and in the current SICA model is maximized.

Objective function:

The Objective function is a sum of squared log residuals defined for the tuning survey indices of biomass and population at age estimates and for the catches at age and catches in tonnes of the different seasonal fisheries defined above.

$$WSSQTotal = SSQCapt_{age} + SSQCapt_{weight} + SSQSurveys_{age} + SSQSurveys_{weight}$$

Where residuals to the catches at age ($SSQCapt_{age}$) are:

$$\sum_{ages}\sum_{1987}^{2006}\sum_{p=1}^{5}\lambda_{a,y,p}\cdot\left(Ln(C_{a,y,p}/\hat{C}_{a,y,p})\right)^2$$

With p referring to the following fisheries:

p	Fishery
1	Winter Frech Fishery
2	Spring-French
3	Spring-Spanish
4	2nd Half of the year-Spain
5	2nd Half of the year-France

and catches in weight are just based on the comparison of SOPs of modelled catches and the actual catches

In addition

for DEPM and Acoustics population at age estimates the fitting is

$$\sum_{ages}\sum_{year}^{2009}\sum_{v}^{surveys}\lambda_{a,y,v}\cdot\left(Ln(U_{a,y,v}/\hat{U}_{a,y,v})\right)^2$$

Where the modelled estimate is:

$$\hat{U}_{a,y,v} = Q_{a,v}\cdot\overline{N}_{a,y,v} = Q_{a,v}\cdot\frac{\hat{N}_{a,y,e}\cdot e^{-\alpha_v\cdot Z_{a,y,e}}}{(\alpha_v-\omega_v)\cdot Z_{a,y,e}}\cdot\left(1-e^{-(\alpha_v-\omega_v)\cdot Z_{a,y,e}}\right)$$

Where, suffix ***v*** refers to acoustic or DEPM surveys, suffix ***e*** refers to the spring period, ***a*** and ***y*** for age and year. *W* is mean weight, *Z* is total mortality and *N* the population in numbers. For Qflat model a single Catchability Q_v for all ages is fitted and if desired catchability can be set equal to 1 (when the survey is taken as absolute estimator of abundance). Suffix ***a*** reaches for acoustics age 2+ until 1999 and subsequently to age 3+ as for the whole DEPM series.

And for the aggregate indices of acoustic or DEPM the index is modelled as (omitting Vulneravility):

$$\hat{U}_{y,v} = \sum_{ages} Q_{a,v} \cdot \overline{N}_{a,y,v} \cdot W'_{a,y,v} = \sum_{ages}\left[Q_{a,v} \cdot \frac{N_{a,y,e} \cdot e^{-\alpha_v \cdot Z_{a,y,e}}}{(\alpha_v - \omega_v) \cdot Z_{a,y,e}} \cdot \left(1 - e^{-(\alpha_v - \omega_v) \cdot Z_{a,y,e}}\right) \cdot W'_{a,y,v} \right]$$

where no additional catchability parameters appear.

Weighting factors: tunning data and fishery catches at age can be weighted.

Fishery weighting factors were set proportional to the catches they actually produce, and were set relative to the Spring Spanish fishery due the fact it has usually produced the largest catches. Weighting factors for the catches at age were set equal to 0.02 for age 0 in any fishery since this catches are not considered to be separable (this is they are taken independent of the other ages and are very noisy. For older ages weighting factors were equal to 1, except for age 3+ which receives a Wfactor=0.1 (as historically set for the tuning the standard ICA given their low percentage in the catches ICES -2005-).

Weighting factors for the DEPM and acoustics were set equal to those used in ICA (=0.5 for each age). Potential correlation among ages in catches or the surveys are accounted for by correcting the weighting factors as in the standard ICA implementation.

The catch and survey biomass estimates by the model were fitted directly without any weighting factor, therefore acting as a penalty when the total sum of products of the modelled age structured values diverges from the biomass observations.

3. Results

a) Analysis of Z by ANOVA:

Table 2 shows that estimates of Z do not differ statistically between surveys within years (Models A1).

Mean Z estimates by periods for each survey are shown in Table 1b by age groups (bottom lines). The Z estimates in recent years are lower than in previous years for both surveys (ANOVAs in Table 3, Models A2), as displayed in Figure 1 and shown in Table 4 (pooling both surveys together).

Older anchovies show higher mortalities than recruits (age 1). Examining the individual results by surveys in Table 1b, this is clear for the DEPM survey, but for acoustics this is less evident for the fishing periods than for the fishing ban period. In table 3b it is shown that the interaction *Survey*Fishing*Old* is at the edge of being statistically significant, but it does not overpass the threshold of α=5%, we follow the analysis assuming this is not a significant interaction.

b) Linear models of Total mortality based on regression on the fishing intensity

Significant relationships of total mortality versus the relative catches between surveys were found for the total population (Table 5 and Figure 2). The intercept of that model gives the estimate of Natural Mortality for all ages (Z 1+) at about 1 with a CV of 20%.

Z for ages 1 and 2+ also showed significant relationships with the relative catches taken between surveys (Table 6) and the final retained model indicated significant differences in the intercept by ages (by Old covariate), pointing out to a M1=0.70 and M2=1.41, with CV around 30%.

In these cases, as for the ANOVA analysis above, survey did not affect the results, however the slope for Relative catches might change with survey as indicated in Table 6b by the interaction *Survey*Old*RCsurvey2* which is at the edge of being statistically significant, but as it did not overpass the threshold of α=5%, we followed the analysis assuming this is not a significant interaction.

Results for other procedures of estimating the Relative Catches to the survey abundances (RC) were totally parallel to the analysis resulting for the RCSurvey2 and their estimates for M1+, M1 and M2+ follow in the text tables below:

Global Mortality M1+

RC estimator	RCjoint	Rcsurvey	RCsurvey2
CONSTANT (= M1+)	**0.720**	**0.906**	**1.012**
Standard Error	0.175	0.190	0.207
CV	24%	21%	20%
RC slope coefficient	**2.016**	**1.363**	**1.357**
Standard Error	0.407	0.389	0.530
CV	20%	29%	39%
R-Squared	52%	35%	22%
Standard Error of Est.	0.497	0.577	0.630
Slopes by surveys			
Acoustic	2.007	2.593	2.545
Standard Error of Est.	0.857	1.099	1.529
DEPM	2.004	1.283	1.220
Standard Error of Est.	0.487	0.467	0.648

And by ages:

RC estimator	RCjoint	Rcsurvey	RCsurvey2
Parameter	Estimate	Estimate	Estimate
CONSTANT (= M1)	**0.717**	**0.722**	**0.698**
Standard Error	0.165	0.159	0.185
CV	23%	22%	27%
OLD (additional component for M2+)	**0.623**	**0.603**	**0.717**
Standard Error	0.203	0.199	0.213
CV	33%	33%	30%
M2+	**1.340**	**1.326**	**1.415**
Standard Error	0.262	0.254	0.282
CV	20%	19%	20%
RC slope coefficient	**1.295**	**1.126**	**1.417**
Standard Error	0.270	0.219	0.360
CV	21%	19%	25%
R-Squared	47%	50%	41%
Standard Error of Est.	0.689	0.672	0.731
Slopes by surveys			
Acoustic	0.602	1.112	0.860
Standard Error of Est.	0.732	0.978	1.148
DEPM	1.342	1.056	1.340
Standard Error of Est.	0.747	0.237	0.410

It is worth noting that the analysis of the Acoustic survey per se did not show significant relationships of Z with any RC, nor significant difference across ages OLD.

c) Integrated catch at age analysis.

Figure 4 shows that, under the assumption of the DEPM providing absolute estimates of biomass and population at age and allowing the estimation of catchabilities at age for the Acoustic survey, SICA is optimised at a constant natural mortality around 1.2-1.3 (Figure 4). This result confirms previous estimates of Natural mortality for this anchovy based upon the same assumptions. The negative correlation between M1+ and F is noticeable (Figure 4 bottom panel). This fitting as results in catchabilities at age for the acoustic survey of Q1=1.18 and Q2+=2.24. And, despite the DEPM is taken as absolute estimator, de facto estimates of catchabilities at age for this survey result in Q1=0.9, Q2=1.5 y Q3+=0.94. So in both cases catchability at age 2 is far higher that at age 1.

Q	**Parameter**	**Age 1**	**Age 2**	**Age 3+**
1	Q(DEPM) *de facto* =	0.8997	1.4971	0.9437
	P(Q=1)	0.3375	0.0000	0.4804
See →	Q (Acoustic)=	1.2421	2.3350	2.5033
	P(Q=1)	0.0685	0.0000	0.0007

Figure 5 (right panels) shows that taking both surveys as relative indexes but assuming Qflat catchabilities at age, SICA is optimised at a constant natural mortality around 0.8, although the surface is quite flat between M= 0.6 and 1.1. On the other hand, when searching for a pattern of M1 and M2+, the RSSQ surface suggest that the lower the M1 the better, although results are all very similar for values of M1 lower than 0.7, showing in all cases M2+ around 1.1.

The *de facto* catchabilities by ages, when a single M_{1+} is estimated, still suggest that they should be higher for age 2 than for age 1. Here is the results for optimization at M1+=0.8:

Joint Qflat Q	De facto	Age 1	Age 2	Age 3+
1.7323	Q(DEPM)=	1.5710	2.3163	1.4167
	P(Q=1)	0.0002	0.0000	0.0003
2.9166	Q (Acoustic)=	2.2674	3.5457	3.1566
	P(Q=1)	0.0000	0.0000	0.0003

The *de facto* catchabilities by ages when a pattern of natural mortality at age is allowed are, taking as an example M1=0.6 (with resulting M2+=1.14):

Joint Qflat Q	*De facto*	Age 1	Age 2	Age 3+
1.7321	Q(DEPM)=	1.6945	2.0207	1.5020
	P(Q=1)	0.0000	0.0000	0.0001
2.9204	Q (Acoustic)=	2.4250	3.1048	3.4772
	P(Q=1)	0.0000	0.0000	0.0001

Which show a higher conformity with the joint catchability factor (Figure 6), particularly for the DEPM, whilst the Acoustic seem to suggest increasing catchabilties at age.

Finally, for the purposes of crossed discussion with the results of the linear model above, a direct minimization of the SICA model for a pattern of natural mortality at ages fixed at M1=0.7 and M2+=1.35 was run. The pattern of catchabilities found is quite similar to the previous case.

Joint Qflat Q	*De facto*	Age 1	Age 2	Age 3+
1.5197	Q(DEPM)=	1.4644	1.7232	1.3751
	P(Q=1)	0.0010	0.0000	0.0009
2.5584	Q (Acoustic)=	2.0731	2.6468	3.2750
	P(Q=1)	0.0000	0.0000	0.0001

4. Discussion

The closure of the anchovy fishery allows estimating an average rate of natural mortality for all ages (M1+) at about 0.83 (pooling all survey estimates together, ANOVA approach) with a CV of 22% or around 0.91 (CV of 21%) with the regression model on RCsurvey (but the mean value may range between 0.7 and 1 depending upon de concrete RC estimator). SICA model also points out towards an optimum fitting for M1+ around 0.8, but with very similar fittings in the range of M1+ between 0.6 and 1.1. The analysis therefore suggest lower M1+ values than the former estimates of 1.2 for the Bay of Biscay anchovy which had been deduced under the assumption of the DEPM providing unbiased estimates of the absolute level of the population (and verified again in this paper in Figure 4). For the same level of total mortalities Z, this result implies fishing mortalities higher than formerly assessed, i.e. higher impact of the fishery on the stock.

The analysis also provides evidence that the level of natural mortality is higher for the ages 2+ than for age 1.The linear modelling of Z on the relative catches (RC) points out M1 and M2+ around 0.7 and 1.35 respectively, being the difference always significant and insensitive to the concrete RC estimator used for the analysis. The analysis certainly depends upon the assumption of no differential catchabilty by ages in the surveys. SICA modelling under such assumption (the Qflat catchability model) results in optimum fittings for M1 values lower than 0.8 and M2+ around 1.15; i.e. quite parallel pattern of natural mortality at age as that shown by the linear models above. As pointed out before in mat and methods, we can not distinguish between differential catchabilities at age or differential natural mortalities by ages. In previous

ICA assessments made for this anchovy in ICES, the assumption of a constant natural mortality at age, led to infer a pattern of catchabilities at age in the surveys by which catchability at age 2 was double of that for ages 1; a result hard to be acceptable. Now, under the assumption of constant catchability at all ages SICA shows optimum fittings for differential natural mortalities at ages. The SICA fitting with Qflat accommodated rather successfully to a single catchability for all ages (Figure 6), beside some unresolved discrepancies (as the seemingly remaining increasing pattern of catchability at age for the acoustics). This shift in the assumptions of catchabilities by age in the surveys from the original ICA type of analysis to the current SICA Qflat implementation supposes a reduction of the number of parameters to be estimated from 7 parameter, i.e. 6 catchabilities (2-Surveys * 3-Ages) and 1 natural mortality, to 4 parameters, 2 catchabilities (1 by survey) and 2 natural mortalities (1-M1 and 1-M2+) So the current approach is parsimonious and should be preferred over the former one (Cotter 2004), implying less assumptions (fewer catchabilities), and, at the same time, resulting in a better fitting to the actual observations of the population at sea (lower RSSQ in absolute terms, Figure 5). With this approach the assessment is more heavily fitted (anchored) to the actual observations provided by the surveys than formerly.

These results suggest therefore that Natural Mortality may increase with age for anchovy, particularly after its second spawning, being anchovy an intermediate small pelagic fish between capelin (which die after it first spawning) and sardines or sprats. This finding is similar to the one shown for sandeels (Cook 2004) and in line with the expectation of increasing mortality at senescence for the short living species (Beverton 1963, Caddy 1991).

The slopes of the linear models of Z on the relative catches between surveys have always been above 1, usually around 1.3 or even higher depending on the concrete type of analysis. As far as that common slope is indicative of the joint catchability of the two surveys the analysis suggests that the surveys tend to overestimate the absolute level of the stock at the sea. However, significant difference from a slope of 1 is only attained for the case of RCjoint; so it is only when using a synthetic indication of the fishing intensity from both surveys when the divergence from the catchability of 1 becomes significant. *Similar results are found when the analysis of M1+ is made by surveys, but when the analysis made by surveys is for M1 and M2+ a catchability higher than one is just seen for the DEPM, not for the acoustic; at this level the standard error of the slopes become very high; so the power of analysis become very limited.* The assessment with SICA, with Qflat, similarly results in catchabilities higher than one for both surveys either for a single M1+ as for M1 and M2+ pattern. For this assessment, the catchabilities become significantly different from 1 for both surveys. So the question arising from the former analysis is whether the current surveys can give overestimates of the true population or not. For the DEPM this is possible: A recent revision of the spawning fraction (S) for the Bay of Biscay anchovy (Uriarte et al. 2010 submitted) indicates that this parameter was underestimated in the past by about 38%, this would imply that the former DEPM biomass estimates were about 60% above the actual values the DEPM should have provided. This would imply catchability for that survey of about 1.6, i.e. a value in line with our analysis above and particularly very close to those suggested by the SICA (Qflat) analysis.

One caveat of all these analysis is the relative noisy results obtained. The r2 of the regression models are at best around 50% o lower, with high standard errors (of about 0.5). Part of it should be due to observation errors from surveys and errors in the RC estimates, but in addition another source of variability can be due to inter-annual variability in natural mortality according to different predation and so on. This analysis can not discriminate among these source of variability but inter-annual variability in Natural mortality was already pointed out for this stock (Prouzet 1999) and they are expected to happen for all stocks (Vetter, 1988, Cook 2004, Gislason 2010). Even more the higher the natural mortality the higher the variability of M should be (Ref).

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Table 1: Direct Population in numbers at age estimates.(a) and derived total mortality values by age groups (b). The fishery has been closed since July 2005 (just with very small catches in 2006).

a)

DEPM SUVEYS			+ group	ACOUSTIC Surveys		True or +group	+ group
Year\ ages	**1**	**2**	**3 +**	**Year\ ages**	**1**	**2 & 2 +**	**3+**
1987	656	331	142	**1987**			
1988	2349	258	68	**1988**			
1989	347	290	25	**1989**	400.0	**405.0**	
1990	5613	190	40	**1990**			
1991	670.5	290.3	4.8	**1991**	1873.0	**1300.0**	
1992	5571	209.3	16.7	**1992**	9072.0	**270.0**	
1993				**1993**			
1994	2030	874	49.3	**1994**			
1995	2257	329	58	**1995**			
1996				**1996**			
1997	3242.6	482.1	13.1	**1997**	2481.0	**870.0**	
1998	5466.7	759.5	56.3	**1998**			
1999				**1999**			
2000				**2000**	5965.3	682.6	281.3
2001	4362.2	1562.0	123.5	**2001**	4169.7	1325.7	141.1
2002	283.6	621.3	133.8	**2002**	1354.2	2253.5	500.6
2003	1042.0	179.6	74.0	**2003**	1120.8	239.0	114.9
2004	864.0	114.9	28.0	**2004**	2248.6	226.2	126.0
2005	95.1	188.8	8.4	**2005**	131.2	421.7	110.2
2006	998.2	156.5	49.7	**2006**	1365.1	394.5	111.4
2007	901.6	316.7	50.0	**2007**	1437.0	632.0	101.2
2008	461.0	553.0	72.0	**2008**	961.3	811.5	266.0
2009	755.0	267.0	255.0	**2009**	1123.7	365.4	404.3

b) Total mortality values for different age groups and by surveys

ANOS	**DEPM survey series**			**ANOS**	**Acoustic Survey complete serie up to 3+**		
Year	**Z (1-2)**	**Z(1+ 2+)**	**Z(2+ 3+)**	**Year**	**Z (1-2)**	**Z(1+ 2+)**	**Z(2+ 3+)**
1987	0.93	1.24	1.94	**1987**			
1988	2.09	2.14	2.55	**1988**			
1989	0.60	1.06	2.07	**1989**			
1990	2.96	2.99	3.87	**1990**			
1991	1.16	1.45	2.87	**1991**		2.46	
1992				**1992**			
1993				**1993**			
1994	1.82	2.03	2.77	**1994**			
1995				**1995**			
1996				**1996**			
1997	1.45	1.52	2.17	**1997**			
1998				**1998**			
1999				**1999**			
2000				**2000**	1.50	1.55	1.92
2001	1.95	2.08	2.53	**2001**	0.62	0.72	1.08
2002	0.46	1.41	2.32	**2002**	1.73	2.45	3.18
2003	2.20	2.20	2.20	**2003**	1.60	1.43	1.03
2004	1.52	1.63	2.84	**2004**	1.67	1.59	1.16
2005	-0.50	0.35	1.38	**2005**	-1.10	0.27	1.56
2006	1.15	1.19	1.42	**2006**	0.77	0.94	1.61
2007	0.49	0.71	1.63	**2007**	0.57	0.70	1.01
2008	0.55	0.73	0.90	**2008**	0.97	0.97	0.98
2009	NA	NA	NA	**2009**	NA	NA	NA
Mean Z (1987-2004)	1.56	1.80	2.56		1.43	1.70	1.67
Mean M (2005-2008)	0.42	0.74	1.33		0.30	0.72	1.29
mean Z (1987-2008)	1.26	1.52	2.23		0.93	1.31	1.50

Table2: Analysis of Variance for total Z (Z1+) (a) and for Z by ages (Z1 and Z2+) (b)

a) Analysis of Variance for total Z (Z1+) - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Survey	0.00268889	1	0.00268889	0.01	0.9259
B:Year	9.15142	15	0.610095	2.09	0.1468
RESIDUAL	2.33351	8	0.291689		

b) Analysis of Variance for Z by Ages (Z1 and Z2+) - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Year	18.2975	15	1.21983	3.37	0.0022
B:Age	8.19227	1	8.19227	22.63	0.0000
C:Survey	0.66125	1	0.66125	1.83	0.1867
RESIDUAL	10.8617	30	0.362058		

Table 3: Anovas testing the effect of the fishing closures:

a) Analysis of Variance for overall Z (Z1+) - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Fishing	4.88397	1	4.88397	16.28	0.0006
B:Survey	0.00109187	1	0.00109187	0.00	0.9524
RESIDUAL	6.60096	22	0.300044		
TOTAL (CORRECTED)	11.7429	24			

b) Anova for Z by ages (Z1 and Z2+): Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Fishing	6.44179	1	6.44179	14.80	0.0004
Survey	0.0816888	1	0.0816888	0.19	0.6672
OLD	6.25927	1	6.25927	14.38	0.0005
Fishing*Survey	0.000254295	1	0.000254295	0.00	0.9808
Fishing*OLD	0.265792	1	0.265792	0.61	0.4391
Survey*OLD	0.285137	1	0.285137	0.66	0.4231
Fishing*Survey*OLD	0.431941	1	0.431941	0.99	0.3251
Residual	17.4084	40	0.435211		
Total (corrected)	40.4944	47			

c) Anova for Z by ages (Z1 and Z2+): Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Fishing	10.7721	1	10.7721	25.22	0.0000
OLD	6.73276	1	6.73276	15.76	0.0003
Fishing*Survey*OLD	1.47815	1	1.47815	3.46	0.0696
Residual	18.7965	44	0.427193		
Total (corrected)	40.4944	47			

d) Anova for Z by ages (Z1 and Z2+): Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Fishing	12.0275	1	12.0275	26.70	0.0000
OLD	8.19227	1	8.19227	18.18	0.0001
Residual	20.2746	45	0.450547		
Total (corrected)	40.4944	47			

95.0% confidence intervals for coefficient estimates (Z)

Parameter	Estimate	Standard Error	Lower Limit	Upper Limit	V.I.F.
CONSTANT	0.954688	0.141231	0.670234	1.23914	
Fishing	-0.530937	0.10276	-0.737908	-0.323967	1.0
OLD	0.82625	0.193767	0.435983	1.21652	1.0

Table 4: Resulting Mean Z by Fishing periods and ages (pooling survey's estimates). N= No Fishing period. Y= Fishing period

a) Overall Z (Z1+):

Table of Means for Z by Fishing
with 95.0 percent LSD intervals

Fishing	Count	Mean	(pooled s)	Lower limit	Upper limit
N	9	0.827778	0.178589	0.566544	1.08901
Y	16	1.7725	0.133942	1.57657	1.96843
Total	25	1.4324			

b) Z at age 1 (Z1):

Table of Means for Z by Fishing
with 95.0 percent LSD intervals

Fishing	Count	Mean	Stnd. error (pooled s)	Lower limit	Upper limit
N	8	0.3625	0.24546	0.00254421	0.722456
Y	16	1.51625	0.173567	1.26172	1.77078
Total	24	1.13167			

c) Z at ages 2 and older (Z2+):

Table of Means for Z by Fishing
with 95.0 percent LSD intervals

Fishing	Count	Mean	Stnd. error (pooled s)	Lower limit	Upper limit
N	8	1.31125	0.233312	0.969109	1.65339
Y	16	2.28125	0.164976	2.03932	2.52318
Total	24	1.95792			

Table 5: Fitting the total Mortality for the whole population Z (Z1+) as a function of Relative catches index (ModelB1): a) First test of the complete model and b) Retained model after consecutive omission of non significant coefficients.

a) Comparison of Regression lines First test of the complete model fo Z (Z1+):
Multiple Regression Analysis

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.839115	0.340974	2.46094	0.0226
RCsurvey2	2.54546	1.47963	1.72033	0.1001
Survey=DEPM	0.195992	0.460511	0.425596	0.6747
RCsurvey2*Survey=DEP	-1.32534	1.62084	-0.817688	0.4227

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	2.92762	3	0.975875	2.32	0.1041
Residual	8.81523	21	0.419773		
Total (Corr.)	11.7429	24			

b) Comparison of Regression lines Final model for Total Z (Z1+) Multiple Regression Analysis

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	1.01192	0.207075	4.88674	0.0001
RCsurvey2	1.3571	0.530191	2.55964	0.0175

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	2.60345	1	2.60345	6.55	0.0175
Residual	9.1394	23	0.397365		
Total (Corr.)	11.7429	24			

Table 6: Fitting the total Mortality at ages (Z1 and Z2+) as a function of Relative catches index (ModelB1): a) First test of the complete model and b) Intermediate model and c)Retained model after consecutive omission of all non significant coefficients at α=5%.

a) Comparison of Regression lines First test of the complete model fo Z by ages

Analysis of Variance for Z

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	20.0273	7	2.86104	5.59	0.0002
Residual	20.4671	40	0.511678		
Total (Corr.)	40.4944	47			

Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Survey	0.906938	1	0.906938	1.77	0.1906
OLD	3.28212	1	3.28212	6.41	0.0153
RCsurvey2	2.95055	1	2.95055	5.77	0.0211
Survey*OLD	0.770167	1	0.770167	1.51	0.2270
Survey*RCsurvey2	1.40504	1	1.40504	2.75	0.1053
OLD*RCsurvey2	1.10216	1	1.10216	2.15	0.1500
Survey*OLD*RCsurvey2	2.61959	1	2.61959	5.12	0.0292
Residual	20.4671	40	0.511678		
Total (corrected)	40.4944	47			

R-Squared = 49.4569 percent, R-Squared (adjusted for d.f.) = 40.6119 percent
Standard Error of Est. = 0.715317, Mean absolute error = 0.501761

b) Intermediate Linear model for Z by ages: Analysis of Variance for Z

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	18.5341	4	4.63351	9.07	0.0000
Residual	21.9603	43	0.510706		
Total (Corr.)	40.4944	47			

Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
OLD	2.42984	1	2.42984	4.76	0.0347
RCsurvey2	2.20919	1	2.20919	4.33	0.0435
OLD*RCsurvey2	0.135011	1	0.135011	0.26	0.6098
Survey*OLD*RCsurvey2	1.91277	1	1.91277	3.75	0.0595
Residual	21.9603	43	0.510706		
Total (corrected)	40.4944	47			

R-Squared = 45.7694 percent, R-Squared (adjusted for d.f.) = 40.7247 percent
Standard Error of Est. = 0.714637, Mean absolute error = 0.51495

c) Final retained model for Z by age : Multiple Regression Analysis

Dependent variable: Z

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	0.69813	0.185445	3.76463	0.0005
RCsurvey2	1.41715	0.360128	3.93513	0.0003
OLD	0.717108	0.212775	3.37026	0.0015

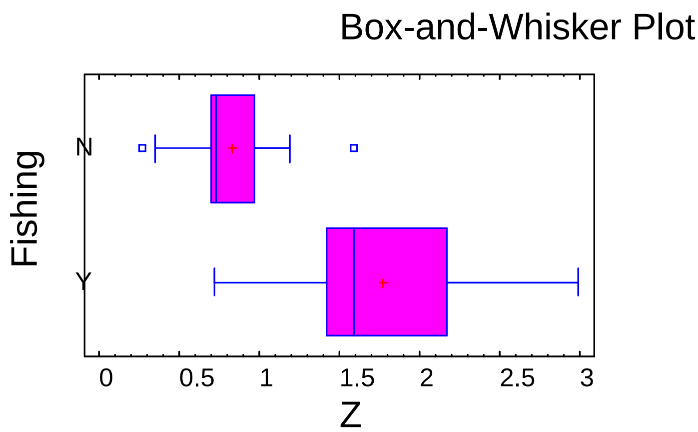
Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	16.4622	2	8.23108	15.41	0.0000
Residual	24.0322	45	0.53405		
Total (Corr.)	40.4944	47			

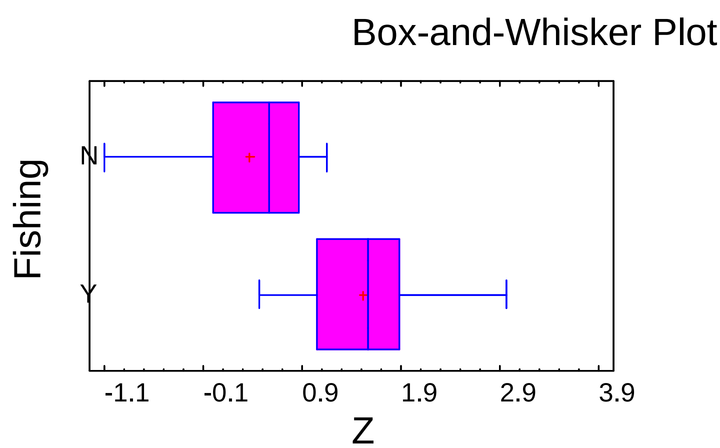
R-squared = 40.6529 percent, R-squared (adjusted for d.f.) = 38.0153 percent
Standard Error of Est. = 0.730787, Mean absolute error = 0.546323

Figure 1: Box and Whisker Plot for Z by ages (pooling survey's estimates).
N= No Fishing period. Y= Fishing period

a) Overall Z (Z1+):



b) Z at age 1 (Z1):



c) Z at ages 2 and older (Z2+):

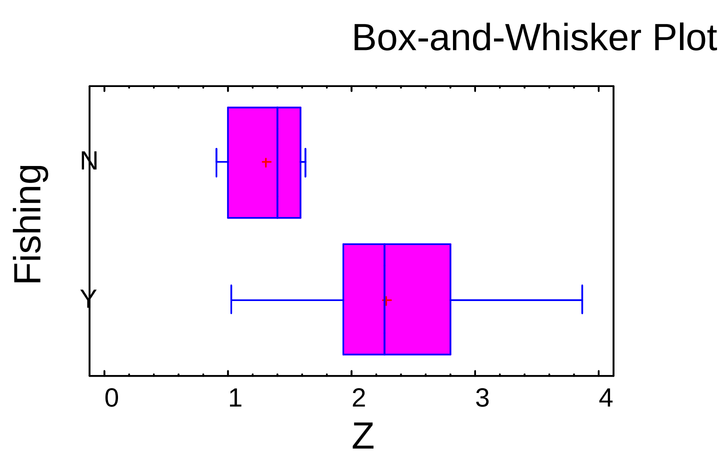
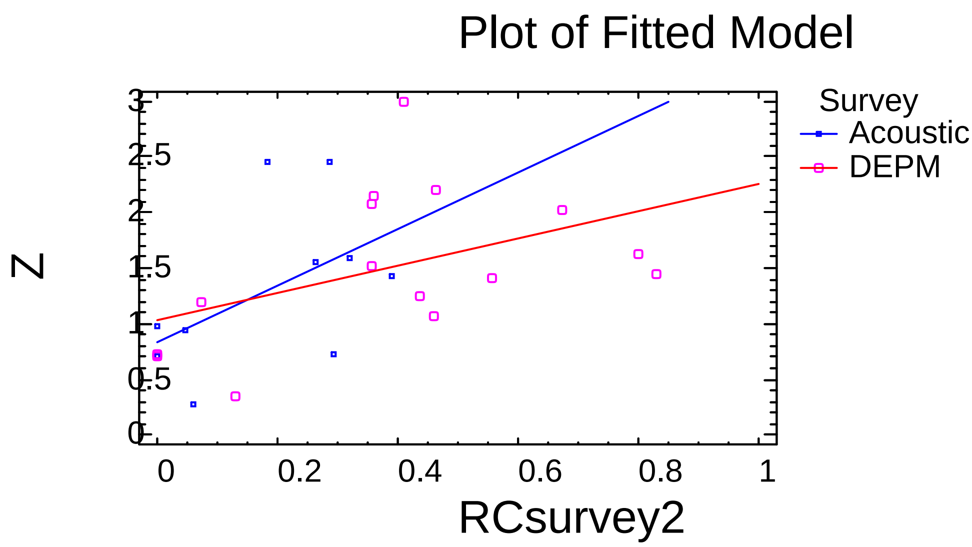
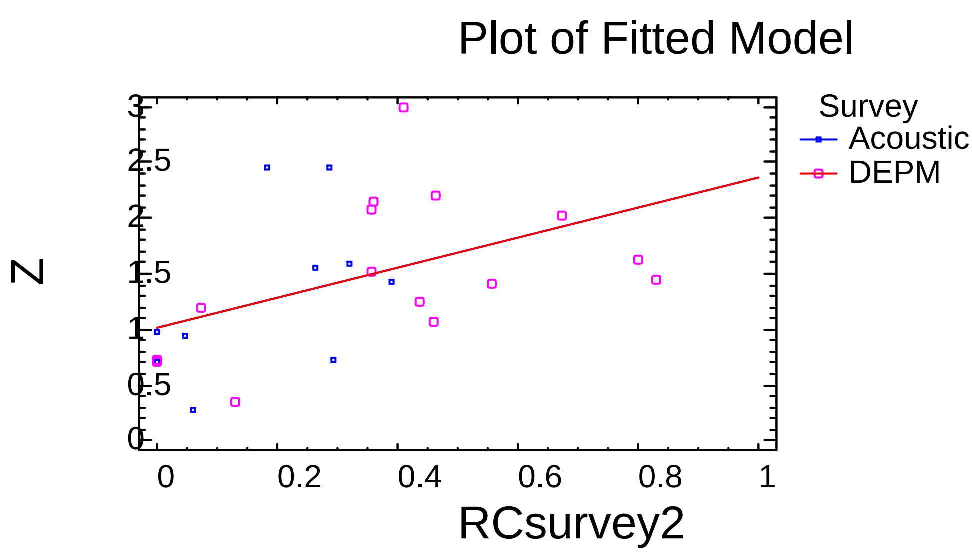


Figure 2: Total Z estimates (Z1+) (Model B1)

a) Fitting of the Original Model B1



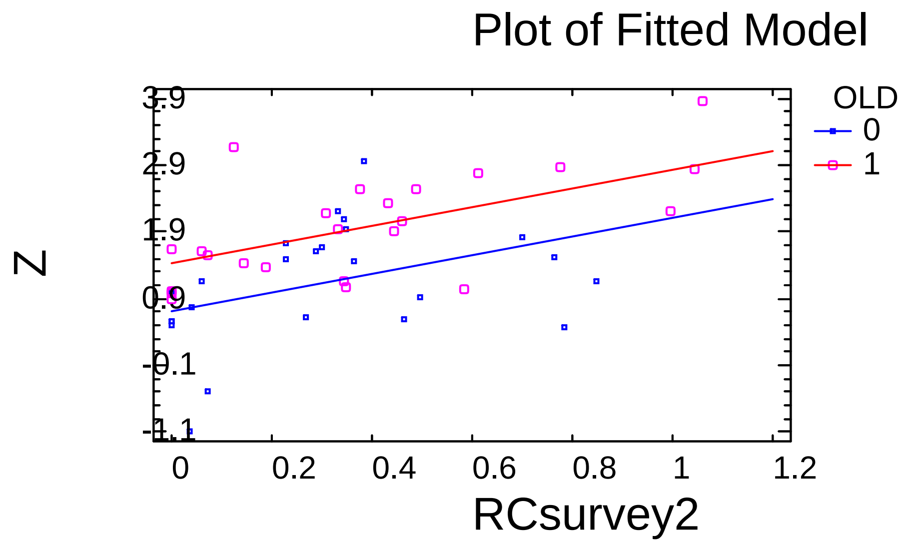
b) Final adjusted model B1 for total Z (Z1+)



d) Residual plot

Figure 3: Final fitted models for the Z by ages as a function of the relative catches between surveys.

a) Fitted model



b) Studentized residuals

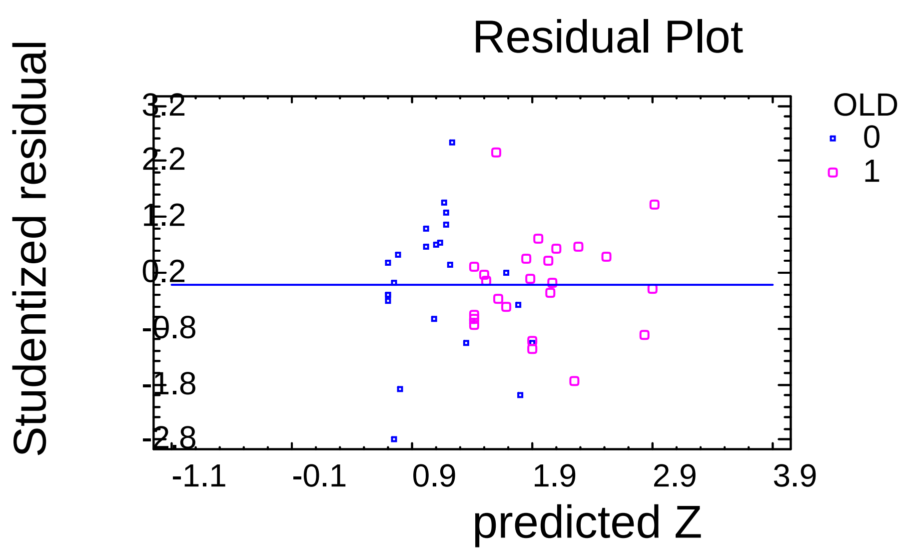


Figure 4: Sum of squares residuals for a range of fixed M1+ for all years and ages according to a SICA assessment based on DEPM providing absolute estimates of biomass and populations at age estimates; and allowing estimating catchabilities at age for the Acoustic survey. Bottom panels has the associated fishing mortality F for each level of M1+

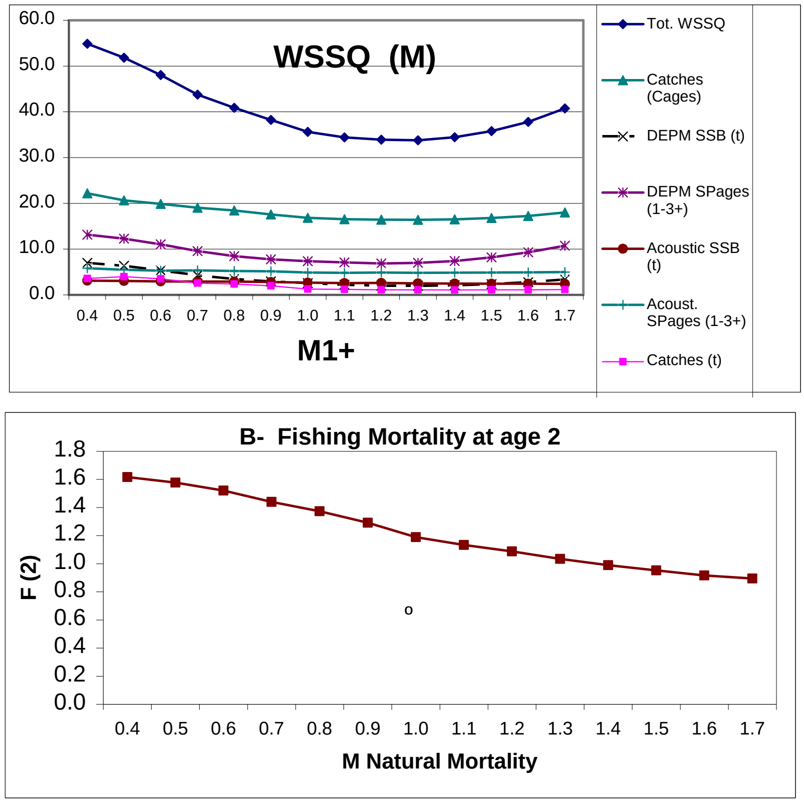


Figure 5: Sum of squares residuals depending on different Natural Mortality assumptions for fixed M for all years and ages (left) and for M1 and M2+ (right), according to a SICA assessment based upon DEPM and Acoustics supplying relative indexes of abundance and having a Qflat catchability model across ages. Bottom panels have the associated fishing mortality F, for each level of M, and in the case of the bottom right panel it also show the value M2+ for each M1 value tested.

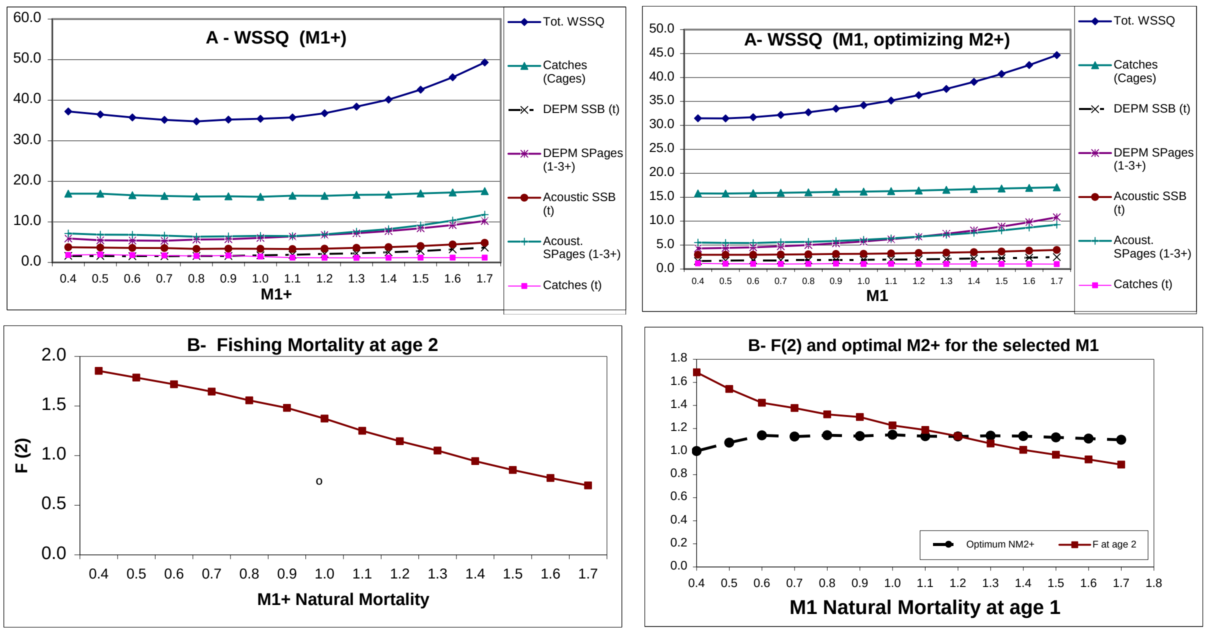


Figure 6: Fitting of the survey population at age estimates for the Acoustic (Left columns) and DEPM (right columns) by the SICA model for a pattern of Natural mortality at age of M1=0.6 and M2+=1.14, with common catchabilities for all ages per survey (Qflat catchability model).